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FINAL TECHNICAL REPORT FOR
ONR CONTRACT N00014-83-K-0454,

"GROWTH, PHYSICAL PROPERTIES, AND DEVICE
CHARACTERISTICS OF $\text{Hg}_{1-x}\text{Mn}_x\text{Te}$ and
 $\text{Hg}_{1-x-y}\text{Cd}_y\text{Mn}_x\text{Te}$ Epilayers"
P. A. Wolff

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The original aims of this research program were:

- 1) To develop techniques for reproducible growth of device quality $\text{Hg}_{1-x}\text{Mn}_x\text{Te}$ and $\text{Hg}_{1-x-y}\text{Cd}_y\text{Mn}_x\text{Te}$ epitaxial layers with controlled carrier concentration and alloy composition in the range $0 < x < 0.2$,
- 2) To measure transport, optical, and other physical properties of the samples grown.

Epitaxial growth of $\text{Hg}_{1-x}\text{Mn}_x\text{Te}$ and $\text{Hg}_{1-x-y}\text{Cd}_y\text{Mn}_x\text{Te}$ layers was performed with liquid phase epitaxy (ref. 1) and vapor phase epitaxy (ref. 2) techniques. LPE growth was done from supercooled solutions by decreasing temperature; VPE growth used the isothermal method with precisely controlled Hg pressure. These experiments were the first demonstration, to our knowledge, of HgMnTe epilayer growth. In exploring different growth conditions, data were accumulated that determine the phase diagram of HgMnTe.

Epilayers were characterized with standard analytic and transport techniques. Low defect densities ($10^3/\text{cm}^2$) were observed in VPE HgMnTe layers. Some bulk HgMnTe crystals were grown by the Bridgman and travelling zone methods. High quality p-n junctions were fabricated in them by annealing. The junctions electroluminesce more efficiently (ref. 3) than comparable HgCdTe junctions and have higher p-type conductivity. Both features are advantageous in device applications.

A continuation of the initial contract (from 7/1/85 to 6/30/87) emphasized luminescence studies and the possibility of achieving laser action in HgMnTe. The proposal also requested support for bulk crystal growth of HgMnTe and CdMnTe (the latter for substrates). These projects were later augmented by doping studies of p-type CdMnTe (refs. 4 and 5). The electroluminescence studies were particularly successful, eventually leading to the demonstration of diode laser action in

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HgMnTe and HgCdMnTe (ref. 6). To our knowledge, this is the first observation of diode laser action in a II-VI semiconductor system. The experimental devices operated in the 5-6u range, but probably could be fabricated to operate at other frequencies in the 2-10u portion of the IR. High optical confinement and low threshold current density were achieved using a double-sided heterostructure configuration. This device has been awarded U.S. Patent Number 4,813,049, entitled "Semimagnetic Semiconductor Laser", with Pictr Becla, Inventor.

In another application of narrow II-VI semiconductors, exceedingly large, Faraday rotations were demonstrated in HgCdTe and HgMnTe (ref. 7). This work has since stimulated an extensive investigation of CO₂ laser Faraday rotation in n-InSb at Lincoln Laboratories.

Beyond addressing the specific goals of the research contract, this program has provided semiconductor crystals to a number of laboratories for basic scientific studies of diluted magnetic semiconductors. Their work is summarized in refs. 8-13.

STATEMENT "A" per Dr. Kenneth Hathaway
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- 2) "Pressure Controlled VPE Growth of Quaternary $\text{Hg}_{1-x-y}\text{Cd}_y\text{Mn}_x\text{Te}$ Epitaxial Layers", P. Becla, P. A. Wolff, R. L. Aggarwal, S. Y. Yuen and R. R. Galayka, J. Vac. Sci. Technol. A3, 119 (1985).
- 3) "Infrared Photovaltaic Detectors Utilizing $\text{Hg}_{1-x}\text{Mn}_x\text{Te}$ and $\text{Hg}_{1-x-y}\text{Cd}_y\text{Mn}_x\text{Te}$ Alloys", P. Becla, J. Vac. Sci. Technol. A4, 2014 (1986).
- 4) "Optical Studies of $\text{Cd}_{0.9}\text{Mn}_{0.1}\text{Te}$ Doped with Au, As, Cu and P Acceptors", J. Misiewicz, P. Becla, E. D. Isaacs, P. A. Wolff, D. Heiman, L. R. Ram-Mohan and J. M. Wrobel, J. Appl. Phys. 63, 2396 (1988).
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